FINAL REPORT

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STUDIES IN HYPERSONIC FLOW THEORY

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SUMMARY

The three specific problems originally proposed have been effectively solved, together with a number of others completed or well under way. Seven publications have resulted from research under the contract, with more to come, and sixteen talks presented at various technical meetings. Two graduate students received their Ph.D. degrees under the contract, and six others were supported in their doctoral research.

RESEARCH COMPLETED

The original proposal listed three basic unsolved problems in hypersonic flow theory, and these were listed as research aims in the contract. All three have been effectively treated, the first two having already led to significant contributions to the scientific literature, and the third nearing completion. Details follow.

Effects of nose bluntness on a slender body. J. Yakura has developed an analytical method, and carried out detailed solutions for the blunted wedge, the blunted cone, and the body of revolution producing a paraboloidal shock wave at infinite Mach number (Publication 1). This work was reported at an international symposium (Talk 4); and the published paper (Publication 2) has excited considerable discussion and been extensively cited in the literature.

Flow past inclined blunt bodies. R. J. Swigart applied a new method to the calculation of hypersonic flow past unsymmetric as well as symmetric blunt bodies in hypersonic flow (Publication 4). This led to refutation of the conjecture that the body is always wet by the streamline of maximum entropy. The theory was presented at a national meeting (Talk 15, Publication 6). It is currently being extended at Lockheed to the calculation of real-gas flows past inclined bodies.

Unsteady hypersonic flow theory. S. McIntosh has solved the problem of general harmonic oscillations of a thin wedge in hypersonic small-disturbance theory. Comparison with the Newtonian approximation has resolved previous difficulties with that method and with the well-known piston theory. This work is being prepared for publication.

In addition to these three original problems, several other lines of research have been pursued, with emphasis on viscous effects in hypersonic flow. A number of publications of completed work have resulted, as well as several problems still being pursued under the current grant that is the successor to the contract:

Viscous effects on blunt bodies. M. Van Dyke has developed a general theory of higher approximations in hypersonic boundary layer theory, and applied it to the sphere (Publication 3). Later, additional examples were treated, and compared with rival theories and with experiment (Publication 5). This work has been reported at two international meetings (Talks 5, 13).

Irreversible processes in dilute gases. J.-P. Guiraud carried out an elaborate theoretical study of the viscosity of mixtures of monatomic gases. This work is currently being issued as a report.

Blunt bodies at low Reynolds number. H. C. Kao has made a critical examination of solutions for viscous hypersonic flow past a sphere throughout the range of Reynolds number from 10 to infinity. Three different methods are applied, correlated, and compared with other studies. This work is now being prepared for publication.

Vortical layer on an inclined cone. A. G. Munson has carried out, to the second approximation, an analytical solution for the thin vortical layer near the surface of an inclined circular cone in hypersonic flow. Comparison is made with other simpler and erroneous treatments. This work is being prepared for publication.

Interaction of entropy and boundary layers. S. Nadir is extending Yakura's work to include the viscous boundary layer. Considerable progress has been made, and the study is continuing.

Seven publications have resulted from this research (with others to follow). These are listed in a subsequent section in chronological order.

OTHER BENEFITS

Talks. Some 16 lectures have been presented by five different members of the research group at technical meetings ranging from local seminars to international symposia. These are listed in the last section in chronological order.

Student support. Eight graduate students, working as part-time research assistants, have carried out all or a portion of their research for the Ph.D. dissertation under the contract. Two have already received their Ph.D. degrees and returned to industry: James Yakura to Hughes in December 1961 and Rudolph Swigart to Lockheed in June 1962. Others will follow later.

Visitors. A brilliant young French theoretician, Jean-Pierre Guiraud was brought from Paris for six months in 1961-62. He worked closely with the research group, carried out research of his own (Talk 11), and gave a one-quarter course in Hypersonic Flow Theory. He prepared extensive notes for that course, which will be issued shortly. Professor Nicholas Rott of U.C.L.A. also spent a day at Stanford as a consultant.

Travel to meetings. Yakura and Van Dyke attended the International Hypersonics Conference in Cambridge, Massachusetts, in August 1961 (Talks 4, 5); Van Dyke attended the Third International Symposium on Rarefied Gas Dynamics in Paris in June 1962 (Talk 13), the Third International Congress of the Aeronautical Sciences in Stockholm in August

1962, the Symposium Transsonicum in Aachen, Germany, in September 1961, and the annual meeting of the Institute of Aerospace Sciences in New York in January 1963.

PUBLICATIONS

1. Yakura, James K.: A Theory of Entropy Layers and Nose Bluntness in Hypersonic Flow. AFOSR-TN-61-1271, Stanford Univ. Dept. of Aero. and Astro. SUDAER No. 110, July 1961.

2. Yakura, James K.: Theory of Entropy Layers and Nose Bluntness in Hypersonic Flow. "Hypersonic Flow Research," F. R. Riddel, editor, Academic Press, 1962, pp. 421-470. (Revised version of Publication 1)

3. Van Dyke, Milton: Second-Order Compressible Boundary-Layer Theory with Application to Blunt Bodies in Hypersonic Flow. AFOSR-TN-61-1270, Stanford Univ. Dept. of Aero. and Astro. SUDAER No. 112, July 1961. Published in "Hypersonic Flow Research," F. R. Riddell, editor, Academic Press, 1962, pp. 37-76.

4. Swigart, R. J.: A Theory of Asymmetric Blunt-Body Flows. AFOSR-TN-62-2232, Stanford Univ. Dept. of Aero. and Astro. SUDAER No. 120, May 1962

5. Van Dyke, Milton: A Review and Extension of Second-Order Hypersonic Boundary-Layer Theory. Stanford Univ. Dept. of Aero. and Astro, SUDAER No. 127, June 1962. To be published in Proc. 3rd Internat. Symp. Rarefied Gas Dynamics, Academic Press.

6. Swigart, R. J.: A Theory of Asymmetric Hypersonic Blunt-Body Flows. IAS Paper No. 62-98, Inst. Aerospace Sci., New York, June 1962. To be published in Jour. Amer. Inst. Aero. and Astro. (Extended version of Publication 4).

7. Van Dyke, Milton: Higher Approximations in Boundary-Layer Theory. Part 2. Applications to Leading Edges. Jour. Fluid Mech., Vol. 14, 1962, pp. 481-495.

TALKS

1. M. Van Dyke: "Higher Approximations in Boundary-Layer Theory." Fluid Mech. Seminar, Stanford Univ., 25 April 1961.

2. J. K. Yakura: "Entropy Layers in Hypersonic Flow Past Blunt Bodies." Fluid Mech. Seminar, Stanford Univ., 30 May 1961.

3. M. Van Dyke: "Current Studies in Hypersonic Flow Theory." Space Tech Labs., 1 June 1961.

4. J. K. Yakura: "A Theory of Entropy Layers and Nose Bluntness in Hypersonic Flow." ARS-AFOSR International Hypersonics Conference, Cambridge, Mass., 16-18 August 1961.

5. M. Van Dyke: "Second-Order Boundary-Layer Theory for Blunt Bodies in Hypersonic Flows." ARS-AFOSR International Hypersonics Conference Cambridge, Mass., 16-18 August 1961.

6. J. K. Yakura: "Entropy Layers in Hypersonic Flow." Douglas Aircraft Co., September 1961.

7. R. J. Swigart: "Hypersonic Flow About a Body at Small Angle of Attack." Fluid Mech. Seminar, Stanford Univ., 31 October 1961.

8. M. Van Dyke: "Higher Approximations in Boundary-Layer Theory," Aeronautics seminar, Calif. Inst. of Tech., 20 November 1961.

9. J.-P. Guiraud: "Theoretical Studies of the Non-Linear Propagation of Sound Waves in the Atmosphere. Application to Sonic Booms in a Non-Homogeneous Gas." Fluid Mech. Seminar, Stanford Univ., 14 Nov. 1961.

10. M. Van Dyke: "Recent Advances in Boundary-Layer Theory." Invited lecture, American Physical Society, Berkeley, Calif., 20 November 1961.

11. J.-P. Guiraud: "A Statistical Interpretation of the Phenomenological Theory of Irreversible Processes in Dilute Gases; Preliminary Investigation about Viscosity in Mixtures of Monatomic Gases." American Physical Society, Berkeley, Calif., 20 November 1962.

12. M. Van Dyke: "Recent Hypersonic Flow Research at Stanford." Joint meeting, Rocky Mountain sections IAS and ARS, Denver, Colorado, 19 January 1962.

13. M. Van Dyke: "A Review and Extension of Higher-Order Hypersonic Boundary-Layer Theory." Third International Symposium on Rarefied Gas Dynamics, Paris, 26-29 June 1962.

14. M. Van Dyke: "Shoptalk from Europe." Fluid Mech. Seminar, Stanford University, 2 October 1962.

15. R. J. Swigart" "A Theory of Asymmetric Hypersonic Blunt-Body Flows." Annual summer meeting, Institute of Aerospace Sciences, Los Angeles, June 1962.

16. H. C. Kao: "A Study of Viscous Hypersonic Flow Past a Sphere." Fluid Mech. Seminar, Stanford Univ., 19 Feb. 1963.